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Spatial Disorientation: Causes, Consequences and Countermeasures for the USAF

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SUMMARY

Spatial disorientation (SD) remains a serious drain on USAF resources and personnel. During the ten-year period of 1990-1999, the USAF experienced 36 SD-related Class A mishaps costing a total of $557M and the loss of 44 aircrew. SD is the single most common cause of human-related aircraft accidents. The causes of SD are complex and require an understanding of the types of SD, the physiology and psychology of flight, and the way pilots train for the prevention of SD. Research has shown there are three distinct types of SD—unrecognized, recognized and incapacitating. Each type impacts the pilot in a different way, and each should be thoroughly understood by the pilot before he or she experiences them in flight. Results from a study of the Post-Roll Illusion (Type I), the Graveyard Spin Illusion (Type II), and a report from a pilot who experienced the Giant Hand Illusion (Type III) is presented. Spatial orientation training techniques are included. Finally, the USAF's Spatial Disorientation Countermeasures Program, designed to reduce the number of SD mishaps, is also presented. This program emphasizes shared knowledge across all flying communities, including research in the areas of attitude awareness (visual and vestibular), multi-sensory integration (3-D audio and tactile stimulation), and both ground-based training and flight-based demonstrations.

Although the phenomenon of spatial disorientation (SD) has been described and documented by many, both researcher and aircrew, since the earliest days of aviation, a complete understanding of the complex mechanisms and interactions has remained elusive. The economic consequences alone of SD are enormous, both in cost of lost aircraft and cost of training new aircrew. This paper will provide examples of different types of SD, the interrelationship of SD to loss of situational awareness (LSA), and a brief summary of the US Air Force Research Laboratory's current SD Countermeasures program.

DEFINITION AND TYPES OF SD

One of the most difficult aspects of the SD problem lies in categorizing and defining SD in a manner agreed upon by researchers (Lyons, Ercoline, Freeman, and Gillingham, 1994). Without a precise definition, one cannot be certain that a particular incident qualifies as SD, or is another phenomenon altogether. Accordingly, the most widely used general definition, one that has been accepted by a large number of countries and which will be used here, spatial disorientation (SD) refers to:

> A state characterized by an erroneous sense of one's position and motion relative to the plane of the earth's surface. (Benson, 1978)

This general definition can be slightly modified with words more commonly used by pilots, flight surgeons, and flight physiologists. The modified operational definition is:

> An erroneous sense of the magnitude or direction of any of the aircraft control and performance flight parameters. (Gillingham, 1992)

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Another difficulty regarding categorizing SD lies in the measurement/yardstick used when determining the nature of the SD condition. For example, SD can be broken into misperceptions due to the stimulation of the vestibular, visual, proprioceptive, and cognitive groupings, depending upon the level of stimulation provided to each human function. Each system requires a complex coordination to take place between the appropriate sensory end organ and the human's central processing unit (i.e. the brain). It becomes even more complex when several sensory modalities are used.

A commonly accepted system of categorization uses a more functional approach. The first grouping, describing phenomena that are unrecognized by the individual, is appropriately named Type I SD. The second functional group encompasses recognized phenomena and is labeled Type II SD. The last, and less well accepted grouping includes what are classed as incapacitating events and are listed, surprisingly enough as Type III SD.

An example of Type I SD is the post-roll, or Gillingham Illusion (Ercoline, DeVilbiss, Yauch, and Brown, 2000), which can be summarized by referencing Figure 1.

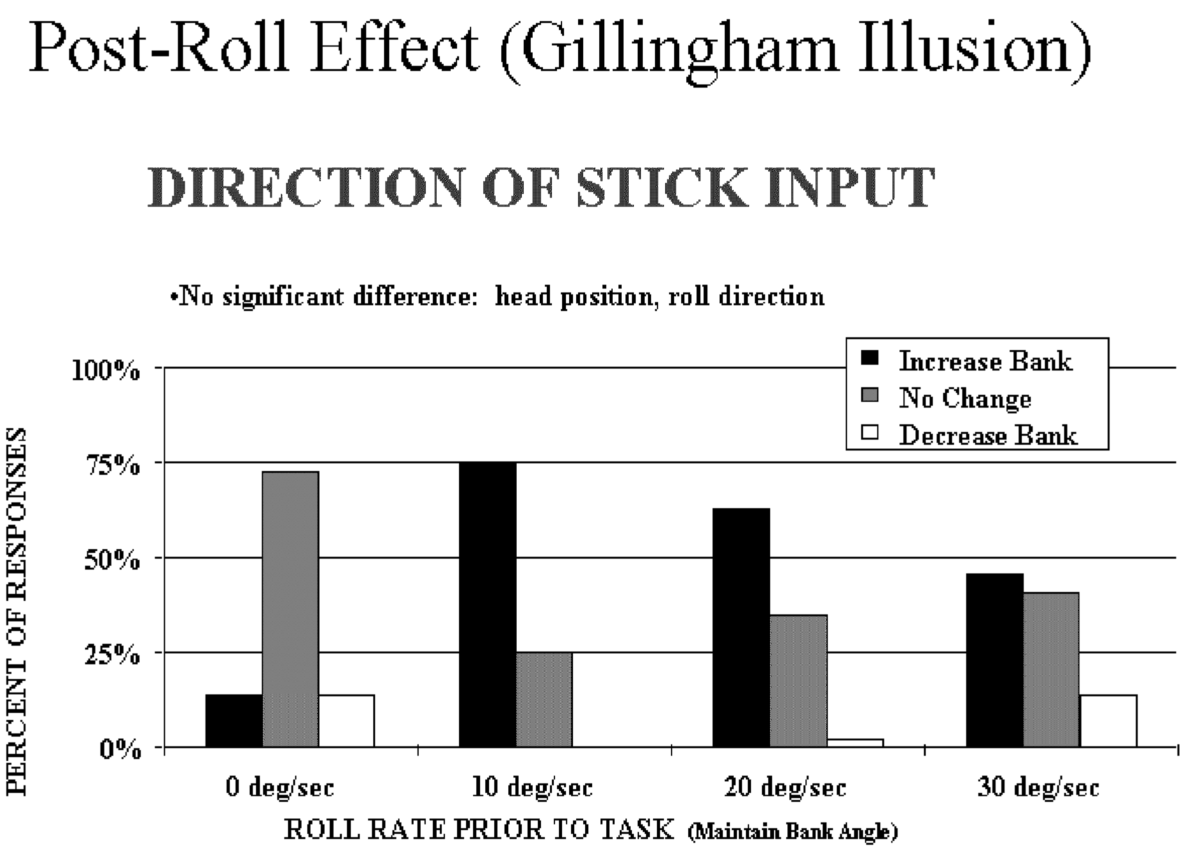

FIGURE 1. Gillingham Illusion Results

Following sustained roll rates of three different magnitudes (four if you consider the null condition as a roll rate), the subject was tasked to maintain the last perceived bank angle. The rates of roll tested were at 10 degrees/sec, 20 degrees/sec, and 30 degrees/sec. There was found a significant difference between the null roll condition and the three different roll rate responses. It was also found that each roll condition, upon stopping, generated a roll sensation contrary to the direction of the initial roll. For example, if the

direction of roll was clockwise, then the sensation perceived by the pilot was counterclockwise, and generated stick inputs that resulted in a clockwise aircraft movement.

Type II SD can be demonstrated by considering the Graveyard Spin (Gillingham and Previc, 1993).

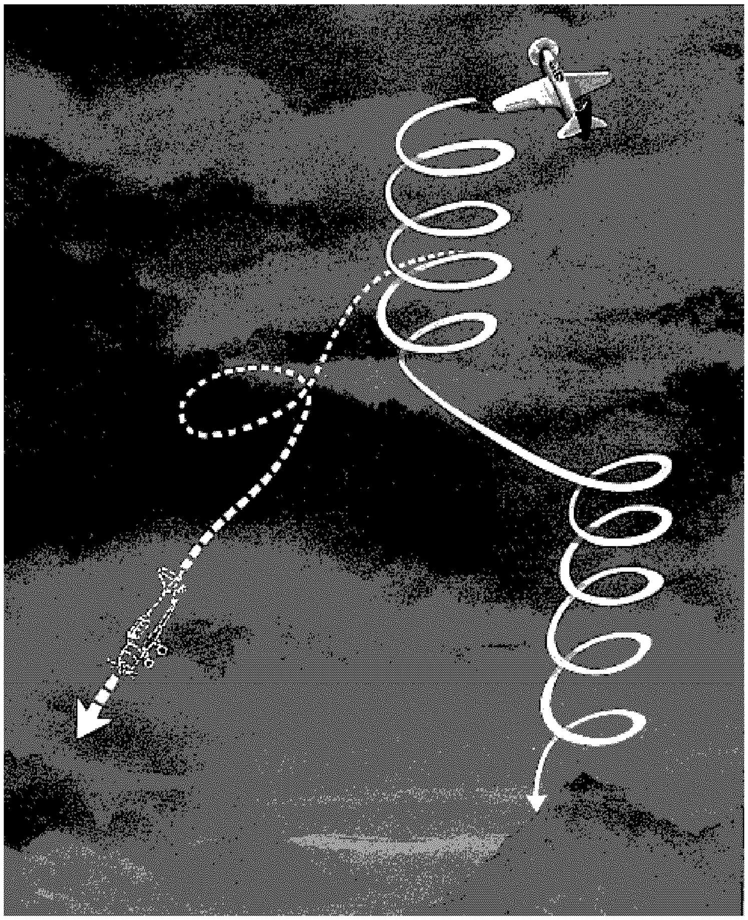

FIGURE 2. Graveyard Spin

In the case of the Graveyard Spin, the pilot enters a spin and stabilizes in yaw (also dampening out the inner ear sensation of rotation). Once control inputs are applied to stop the spin, as the aircraft begins to decrease its angular rotation, the result is a sensation of the aircraft beginning to spin in the opposite direction. When this occurs, and the pilot looks at the aircraft turn needle or compass card, a conflict is now generated between the opposite yaw sensation of the inner ear (erroneous) and the actual yaw displayed by the flight instrument. The pilot must now decide which system to believe—inner ear or eyes. It is a recognized conflict. An important distinction to remember when looking at Type II disorientation is that the individual may not actually recognize at first that they are experiencing disorientation (often the first reaction is to suspect instrument malfunction and "tap" on the instrument case), only that there is a discrepancy between what their internal orientation senses are telling them and what the aircraft instruments are displaying. If resolved properly the pilot will ignore the inner ear sensation of yaw in the incorrect direction and apply controls necessary to arrest the spin.

Type III SD, or incapacitating disorientation can be illustrated by considering the following anecdotal descriptions of the Giant Hand Illusion. Names are withheld at the request of the pilots. The first is a description of a situation that occurred to a T-38 Instructor Pilot:

> "It started routinely. The student and I were coming home on the wing for an instrument approach to cap off a two-ship formation flight that was pretty uneventful. There were layered decks and we were in and out of the tops of a lower deck while getting vectored home. I decided to fly into the actual weather, since I was pretty sure the student was about cooked from the prior descents and I needed some IMC [Instrument Meteorological Conditions] time.
>
> Lead started to go left and descend for the base turn and I followed. Okay, I **tried** to follow. The miserable T-38 was acting up and would not go left. No amount of force, cursing, or pleading would make that baby go left. Lead was kind enough to hold up for me, after I told him to roll out, and I continued to keep my eyes outside to remain visual.
>
> I asked my student to turn the bird left, and together, it worked fine. That crisis passed, I tried to close the gap and discovered the flight control problem was back. I could move the stick up, down, right, but not left. I put all my weight into it, but could not move the stick. I passed controls to the student and he had no problem making it go where he wanted. After a few moments inside with assorted checklists and in-flight guides, I tried one last time before saying the dreaded "E" word and lo and behold: success. Like any good pilot, we flew home, wrote it up and got a big fat CND [Can Not Duplicate], with no FO [Foreign Object] found."

The second incident occurred to a F-16 pilot:

> Visual conditions: clear night, no visible horizon, random stars and ground lights mixed together—difficult to tell the sky form the ground.
>
> "I was number two of a two ship formation flight, lead was already in a turn and I was beginning to move into position. I could not see lead's aircraft, but I could see three of lead's aircraft lights. I was trying to bank my aircraft to move into position. The aircraft would not respond. The harder I tried to push on the stick, the more resistance I felt in my arm. I was trying to bank, but the aircraft seemed like it was too heavy or it just would not bank. I felt as if I was frozen in a roll. I had to stop the rejoin until I could get control of the aircraft by trying to fly instruments. After a short while the aircraft responded to my inputs."

Type III SD is not understood completely. In flight research is probably necessary to duplicate some of these conditions.

CAUSES OF SD

A vast amount of time and effort has gone into understanding the specific causes of SD at the mechanism level, but much of that complex discussion is beyond the scope of this paper. However, in fairly simple terms, it can be asserted that discrepancies between and among the visual, vestibular, somatosensory, and cognitive systems **can** lead to a mismatch between the perceived orientation and the actual orientation. Various contributing factors include attentional anomalies, experience level, expectations, and interpretation of inputs.

It must be noted that simply because this mismatch exists does not automatically necessitate the occurrence of an SD incident. Quite often, the individual crewmember is aware of the mismatch and

chooses, either consciously or unconsciously, to disregard the orientation inputs from his or her internal orientation systems and to focus and rely on the orientation inputs from the aircraft instrumentation. SD incidents occur when the crewmember is either unaware of the mismatch, or aware of the mismatch, but unable to reconcile the cause, or unable to overcome the internal sensory signals and rely on the external orientation information that derives from the aircraft instrumentation.

Much has been written lately about the significant problems associated with the loss of situation awareness (LSA). Because of this attention, a significant amount of resources has been applied to its research to produce a better understand of its consequences. Spatial disorientation (SD) is a large part of situation awareness (SA). Figure 3 illustrates the relationship of spatial orientation (SO) to SA. Another way to look at this relationship is to consider SD a large part of LSA. When one loses SO, they have lost SA. When one losses SA, they have not necessarily lost SO.

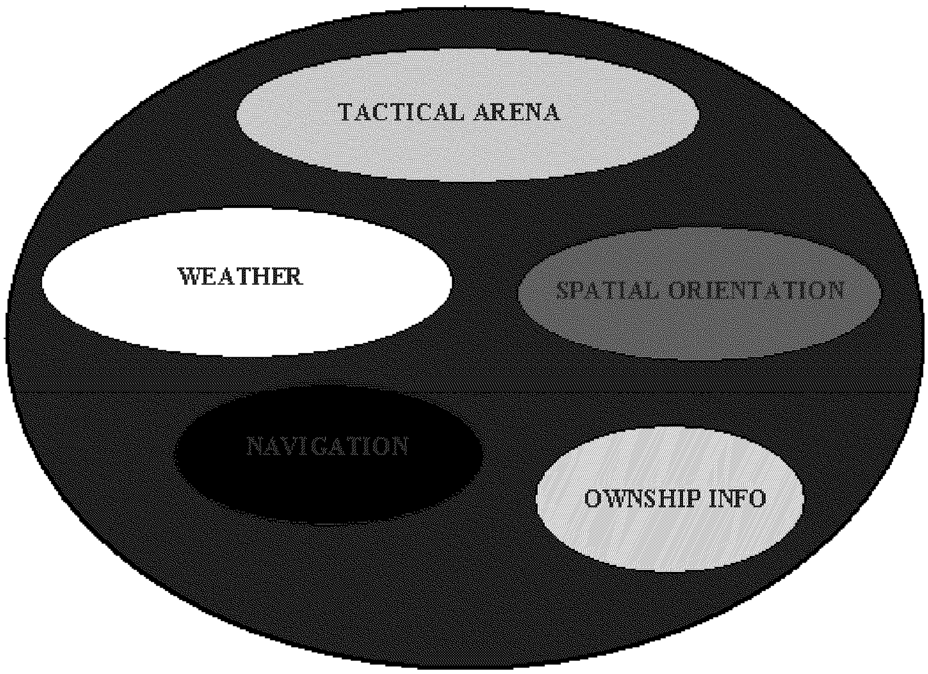

FIGURE 3. Components of Situational Awareness

CONSEQUENCES OF SD TO THE USAF

The consequences of SD can be discussed in many ways, but the economic approach may be the most telling. A standard used for many years is the rate at which a mishap occurs every 100,000 hours of flying time. If at any time during this 100,000 hours of flight, an aircraft is destroyed, a life lost, or more than $1M USD would be required to repair the aircraft, the aircraft accident is called a Class A mishap. Figure 4 shows the Class A mishap rates for the USAF for the period of 1972 to 2000.

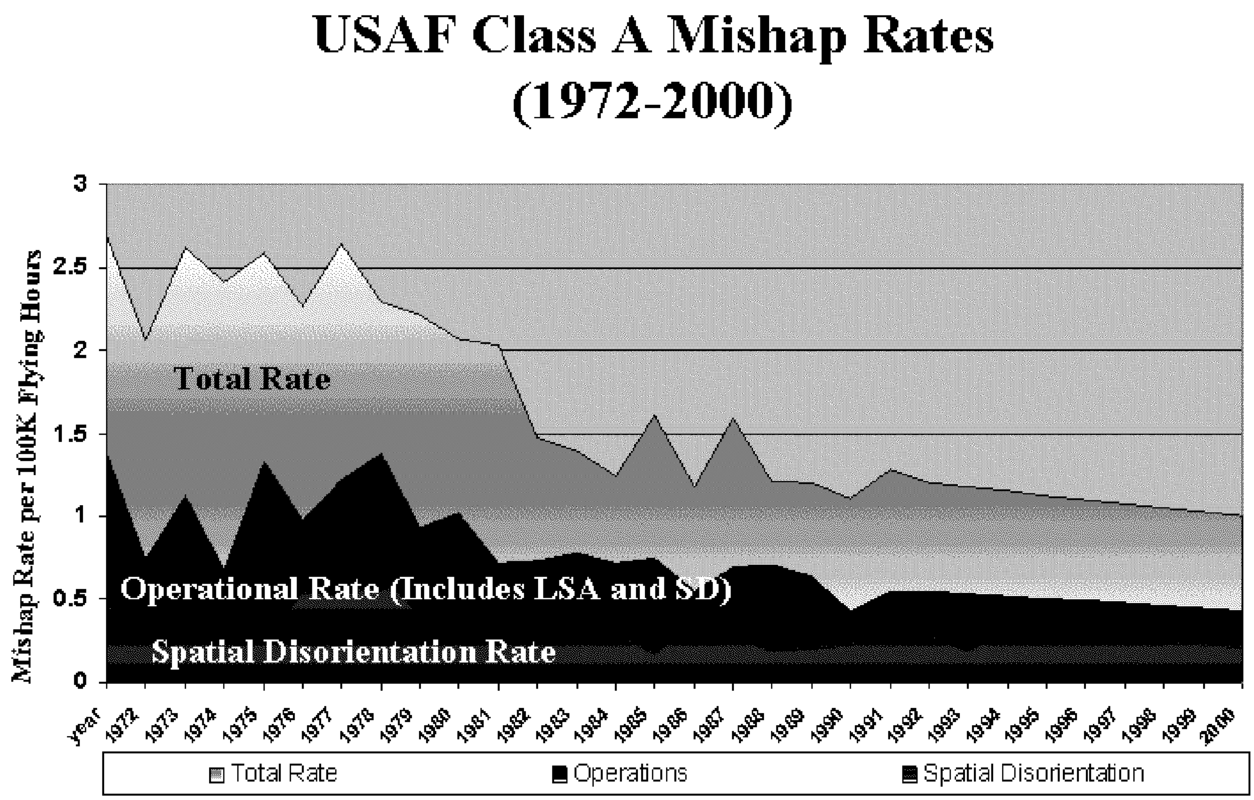

FIGURE 4. Class A Mishap Rates (1972-2000)

As can be seen, the total Class A mishap rate per 100,000 flying hours has been reduced significantly over the past 30 years. Nevertheless, the rate of Class A mishaps due to SD has remained relatively constant when averaged over the 30 year period. Unfortunately, an important item not shown in this figure is the average cost of these accidents over this same time period. Because of the increasing cost per individual aircraft, the actual monetary values have increased. For example, for the period from 1990 to 1999, approximately $557M US dollars worth of aircraft were lost due to SD. As well, and certainly more importantly, 44 crewmembers were killed during this time period. One fact that can be accepted by all, with no disagreement, is that these costs will only increase with the future generations of aircraft. These losses represent a significant drain on the resources of the USAF.

US AIR FORCE RESEARCH LABORATORY'S (AFRL) SD COUNTERMEASURES (SDCM) PROGRAM

In an effort to reduce the SD mishap rate by about 50% within the next 5 years, AFRL initiated a five-year program with a three-pronged approach: training, displays/technologies, and orientation mechanisms research (Heinle, 2000). The intent of the program is to coordinate the multiple and varied research avenues into a coherent research program that will reduce, and eventually eliminate SD as a significant factor in USAF aviation mishaps.

The training research is attempting to develop a metric for the measurement of SD training effectiveness, as well as developing ground and flight based scenarios that will expose aircrew to conditions in which SD is likely to occur. In this way, individuals will be more aware of what SD "feels" like and therefore be more likely to recognize it when it occurs in an operational setting. This will, in effect, allow us to reduce

the number of Type I SD accidents while producing more Type II SD incidents, i.e. situations the pilot can recognize and apply training techniques to prevent from developing into a Class A accident. In addition, the Lab has established the only website dedicated specifically to the reduction and elimination of SD in the world. This public site is designed to be useful for researcher and operator, military and civilian, and is a very useful tool for anyone involved in SD. It can be accessed at www.spatiald.wpafb.af.mil.

The displays and technologies portion of the program is in the process of developing novel and more intuitive methods of presenting orientation information to the aircrew. Here, the projects range from Pathway in the Sky, an integrated alternative symbology set for use as a primary flight reference, through improvements to Helmet Mounted Display symbology and the use of Night Vision Devices, to the integration of visual, auditory, and tactile information into a single orientation suite. All of this research will eventually assist the aircrew in preventing the sensory mismatch that can initiate an SD event, thereby eliminating the Class A SD-related mishap.

Mechanism research has been a classic approach to a solution of the SD dilemma, and it continues to play a significant role in the current research program. Because, however, this type of work generally delivers results after many years, and this is currently a five-year program, therefore the work must focus on immediate issues like the understanding of the Giant Hand phenomenon. An understanding here will go far in complementing and further expanding previously completed mechanism research. The program will rely heavily on collaborative efforts with allies like those at this conference, and basic research funding organizations like the USA's DARPA/DSO and the USAF's Office of Scientific Research.

ROADMAP FOR THE FUTURE

The problem of SD has been intertwined with aviation since the beginnings of manned flight, and only a concerted and coordinated effort will have any impact of significance. The US AFRL SDCM program has concentrated on two primary aspects of the SD issue: discovery/development of a metric to measure SD and the development of tools and techniques useful to aircrew in the very near term. In this way, pilots can improve their life expectancy now, not at some unspecified future date in a soon-to-be fielded aircraft.

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